National Aeronautics and Space Administration

# Is the Sky Really Falling? An Overview of Orbital Debris

October 30, 2015

US Naval Observatory

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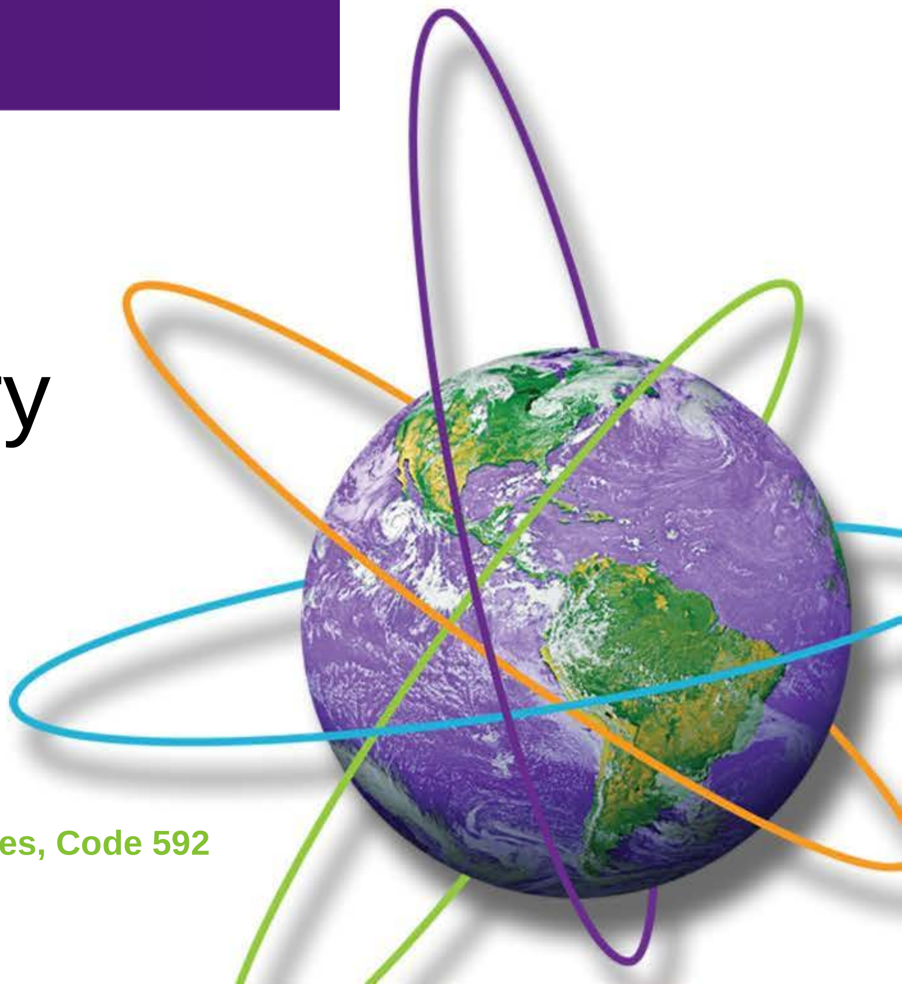
NASA / GSFC Code 592



NASA Goddard Space Flight Center **Orbital Debris Services, Code 592**

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## The Big Questions

- What is orbital debris?
- How can it affect me – why should I care?
- How much is there?
- How is it changing over time?
- What is being done about it?
- What more could we possibly do?

# ORBITAL DEBRIS ENVIRONMENT

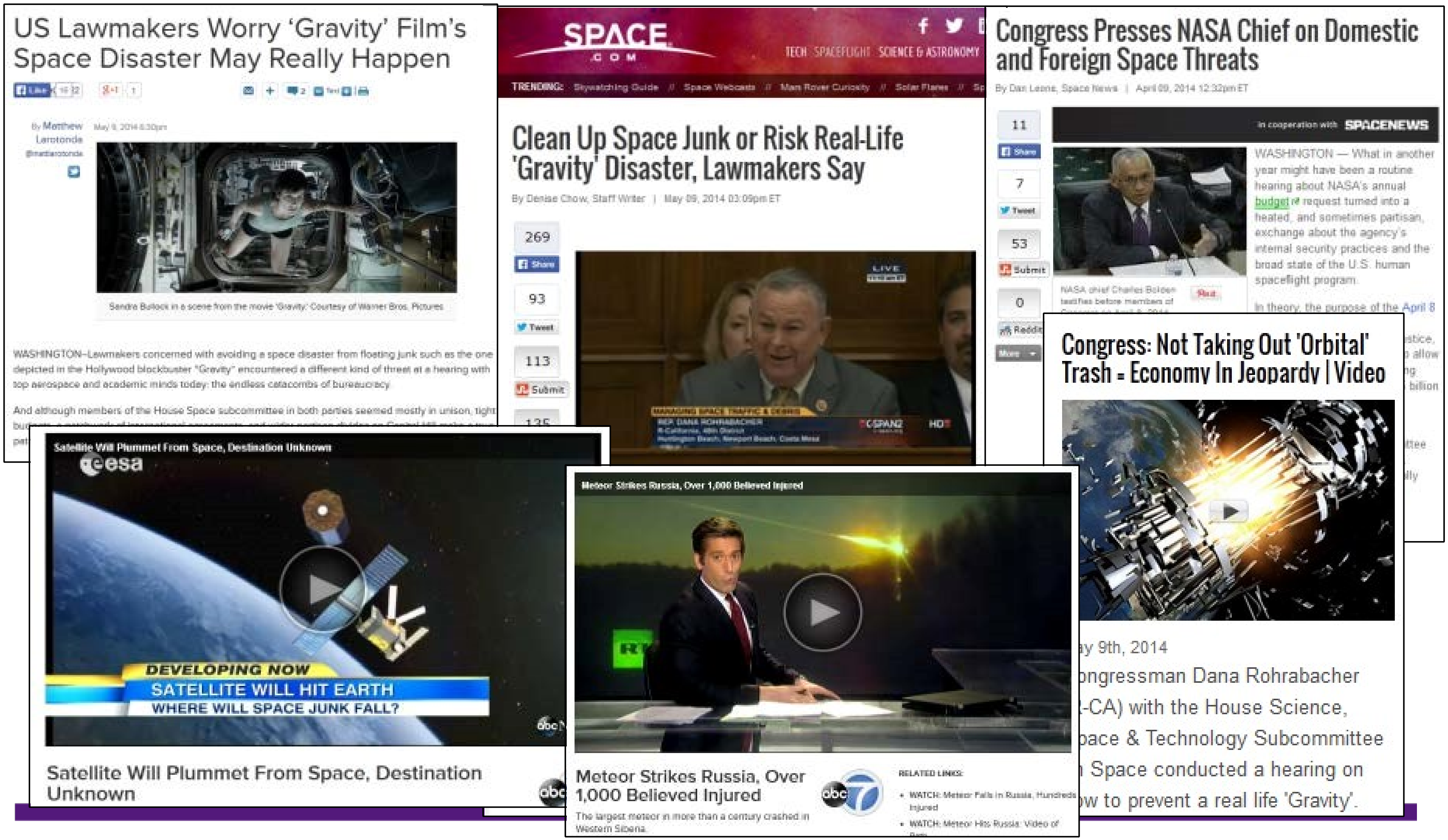

What is orbital debris?

How much stuff is up there?

Where did it come from?

How is it changing over time?

# Recent Articles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By Matthew Larotonda
May 9, 2014 6:30pm
Sandra Bullock in a scene from the movie 'Gravity.' Courtesy of Warner Bros. Pictures
WASHINGTON–Lawmakers concerned with avoiding a space disaster from floating junk such as the one depicted in the Hollywood blockbuster "Gravity" encountered a different kind of threat at a hearing with top aerospace and academic minds today: the endless catacombs of bureaucracy.
And although members of the House Space subcommittee in both parties seemed mostly in unison, tight
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Clean Up Space Junk or Risk Real-Life 'Gravity' Disaster, Lawmakers Say
By Denise Chow, Staff Writer | May 09, 2014 03:09pm ET
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By Dan Leone, Space News | April 09, 2014 12:32pm ET
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in cooperation with SPACENEWS
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ongressman Dana Rohrabacher
-CA) with the House Science,
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Satellite Will Plummet From Space, Destination Unknown
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Meteor Strikes Russia, Over 1,000 Believed Injured
The largest meteor in more than a century crashed in Western Siberia.
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## What is Orbital Debris?

- Orbital Debris is any man-made object in orbit which no longer serves a useful purpose
  - Retired satellites
  - Launch vehicle stages
  - Broken pieces and fragments
  - Tools and discarded objects

- Space Debris includes natural meteoroids as well

# How Much Orbital Debris is Up There?

- On-orbit Environment
  - Currently

~ **22,000** objects ≥10 cm in size

~ **500,000** objects ≥1 cm in size

**Many Millions** of objects <1 mm in size

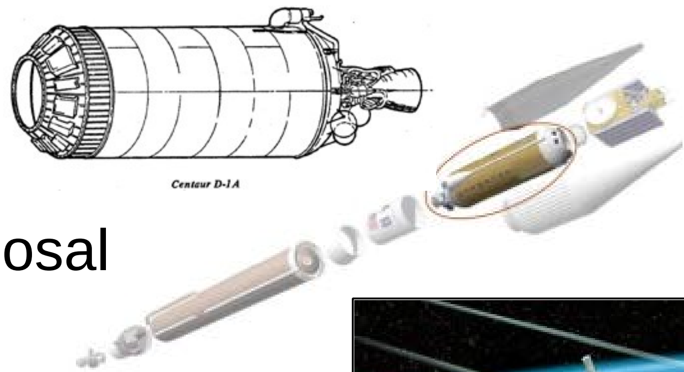
  - Growing rapidly: Already self-propagating
- Spacecraft damage potential
  - Moving at 7 km/s → ~**16,000 mph**!

- ½ $mv^2$ gets to be really big, really fast

- Tracking limitations

# Debris Sources

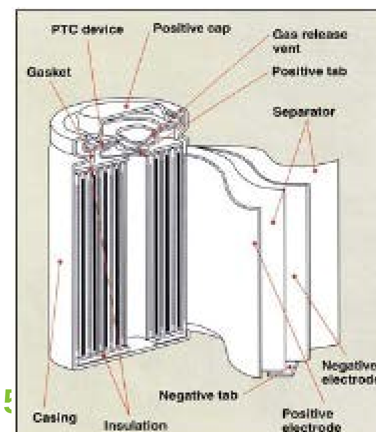
- Launch Vehicles
- Spacecraft
  - Lack of proper disposal
- Collisions
  - Small collisions as well as large
- Explosions
  - Residual fuel and oxidizer
  - Batteries
  - Pressure tanks
- Meteoroids
  - Natural random environment
  - Meteor showers



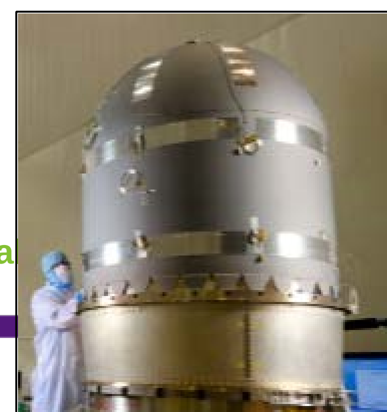



## Explosions

- Batteries
  - Overcharge can generate gas pressure
  - Ni-$H_2$ most susceptible, Li-ion less so
    - Only known US battery explosion was a Ni-Cd
    - Some Li-ion cells have pressure cutoff switches
    - Li-ion must never be recharged after full drain




- Pressure tanks
  - Biprop: fuel and oxidizer can mix because of a leaky valve
  - Overpressure from regulator failure
  - Small debris object impact



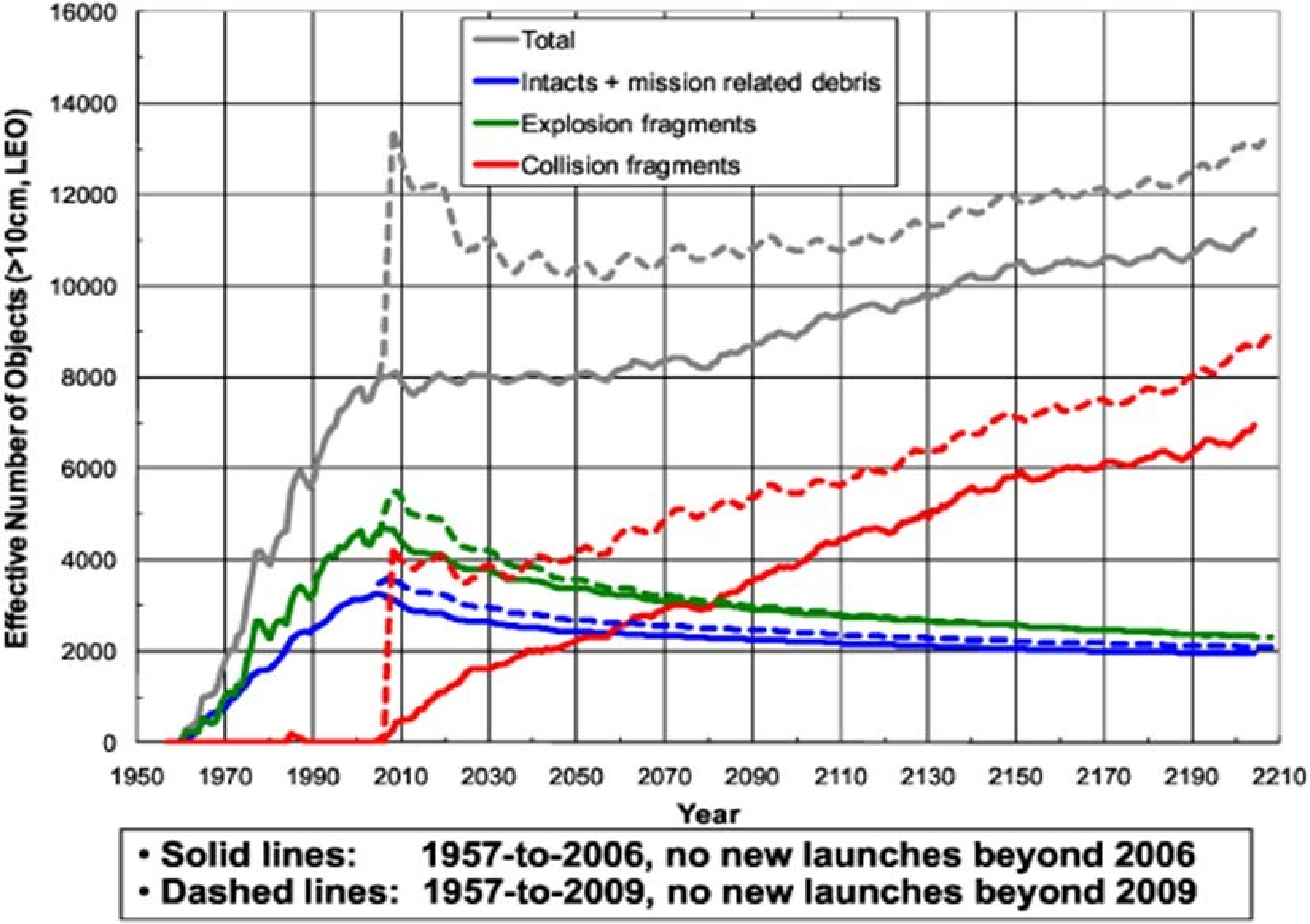
# Recent Major Debris Events

| Vehicle | Type | Date | Objects* | Cause |
|---|---|---|---|---|
| Fengyun 1C (PRC) | Spacecraft | 1/11/2007 1999-025 | ~2850 | Deliberate destruction |
| CBERS 1 (PRC/BRZ) | Spacecraft | 2/18/2007 1999-057 | ~425 | Unpassivated propellant |
| Briz – M (CIS) | Launch Vehicle | 2/19/2007 2006-006 | ~150 | Unpassivated propellant |
| Iridium - Cosmos | Spacecraft x 2 | 2/10/2009 | ~1650 | Collision |
| Briz – M (CIS) | Launch Vehicle | 6/21/2010 2009-042 | ~85 | Unpassivated propellant |

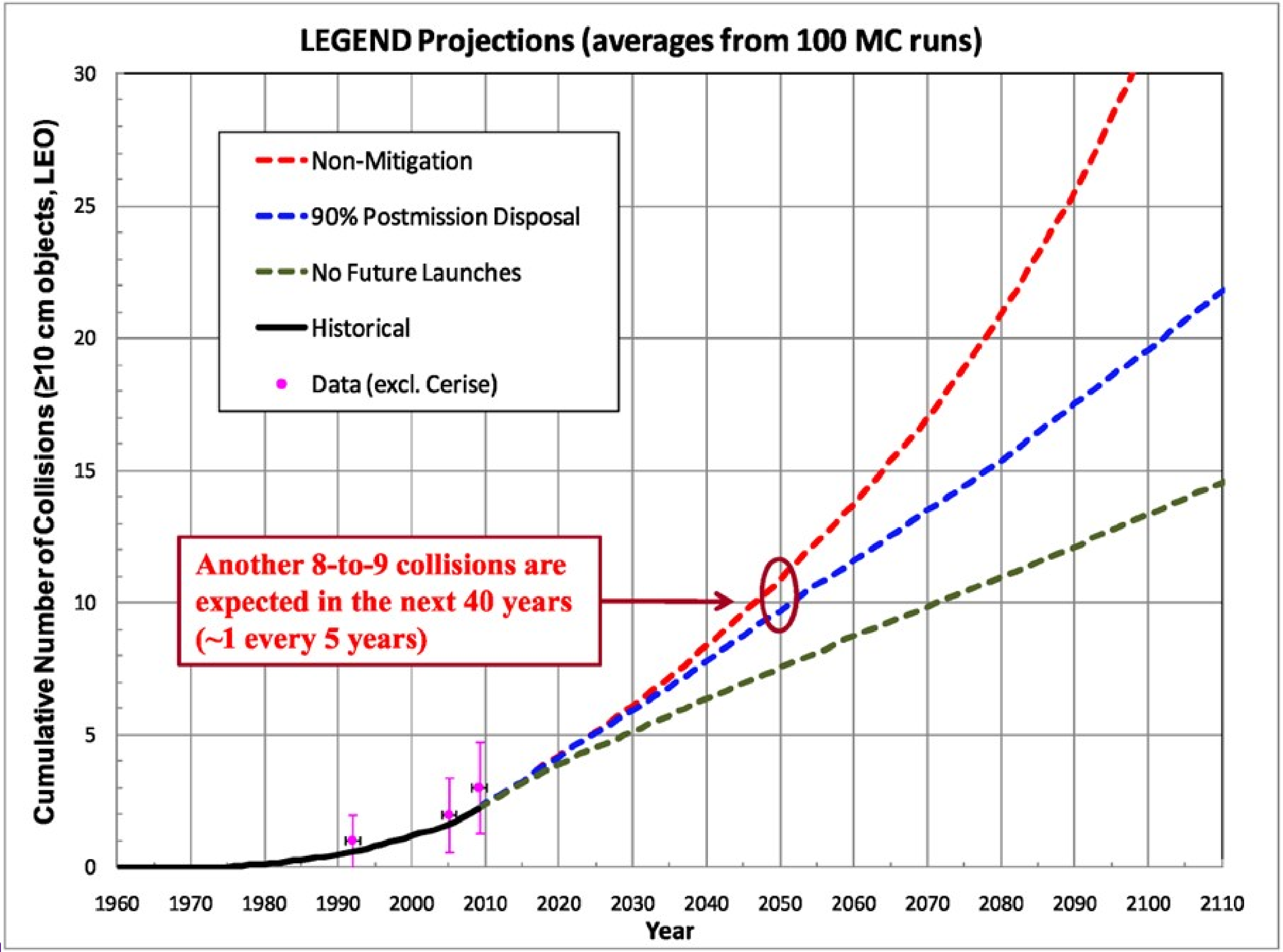
| | | | | |
|---|---|---|---|---|
| Long March 3C (PRC) | Launch Vehicle | 11/1/2010 2010-057 | ~50 | Unpassivated propellant |
| Briz – M (CIS) | Launch Vehicle | 10/16/2012 2012-044 | ~115 | Unpassivated propellant |

* Cataloged objects (> 10 cm)

# Long-term Growth of LEO Debris Population

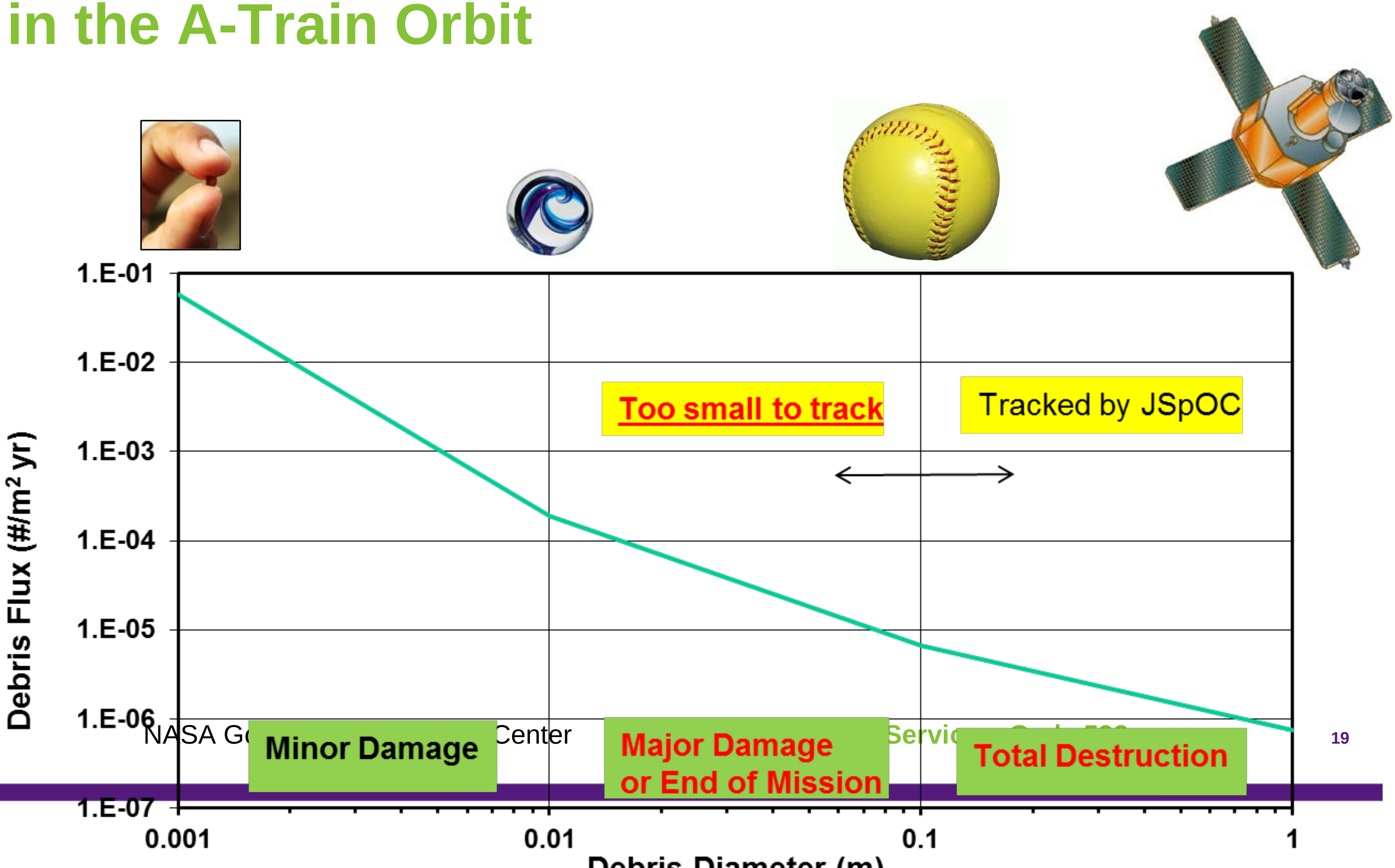

Total
Intacts + mission related debris
Explosion fragments
Collision fragments
Effective Number of Objects (>10cm, LEO)
16000
14000
12000
10000
8000
6000
4000
2000
0
1950
1970
1990
2010
2030
2050
2070
2090
2110
2130
2150
2170
2190
2210
Year
• Solid lines: 1957-to-2006, no new launches beyond 2006
• Dashed lines: 1957-to-2009, no new launches beyond 2009

# Collision Predictions with and without disposal efforts


LEGEND Projections (averages from 100 MC runs)
Non-Mitigation
90% Postmission Disposal
No Future Launches
Historical
Data (excl. Cerise)
Another 8-to-9 collisions are expected in the next 40 years (~1 every 5 years)
Cumulative Number of Collisions (≥10 cm objects, LEO)
Year
0
5
10
15
20
25
30
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110

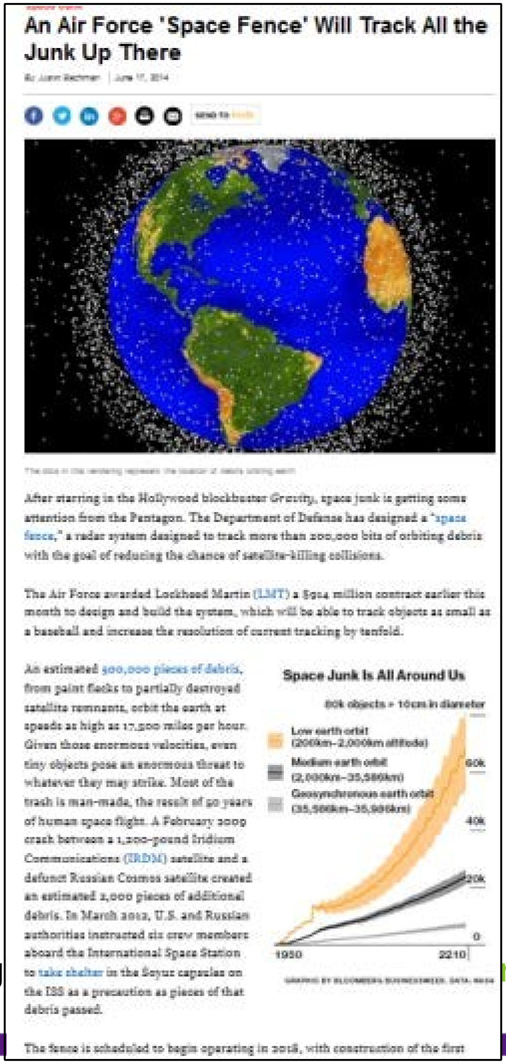
# Debris Flux

## in the A-Train Orbit



# Space Fence

- New S-band radar, located near the equator
- Should be able to detect smaller objects, therefore more objects
- Designed for 5 cm detection
- Slated for operations in 2018



## An Air Force 'Space Fence' Will Track All the Junk Up There

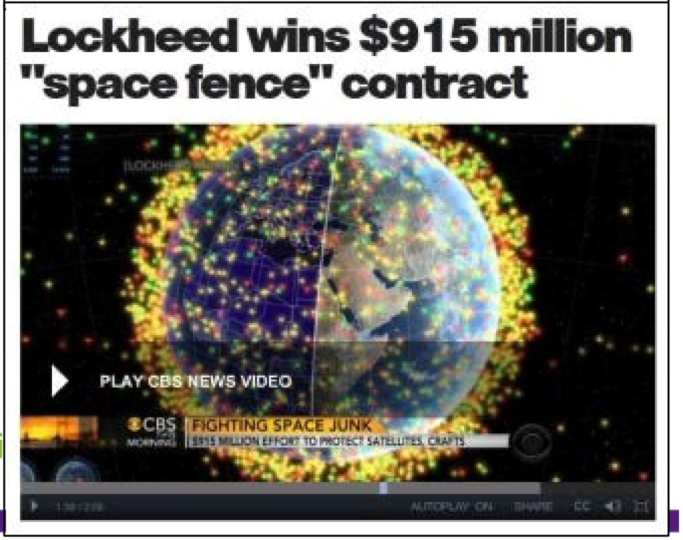
After starring in the Hollywood blockbuster *Gravity*, space junk is getting some attention from the Pentagon. The Department of Defense has designed a "space fence," a radar system designed to track more than 200,000 bits of orbiting debris with the goal of reducing the chance of satellite-killing collisions.

The Air Force awarded Lockheed Martin (LMT) a $914 million contract earlier this month to design and build the system, which will be able to track objects as small as a baseball and increase the resolution of current tracking by tenfold.

An estimated 500,000 pieces of debris, from paint flecks to partially destroyed satellite remnants, orbit the earth at speeds as high as 17,500 miles per hour. Given those enormous velocities, even tiny objects pose an enormous threat to whatever they may strike. Most of the trash is man-made, the result of 50 years of human space flight. A February 2009 crash between a 1,200-pound Iridium Communications (IRDM) satellite and a defunct Russian Cosmos satellite created an estimated 2,000 pieces of additional debris. In March 2012, U.S. and Russian authorities instructed six crew members aboard the International Space Station to take shelter in the Soyuz capsules on the ISS as a precaution as pieces of that debris passed.



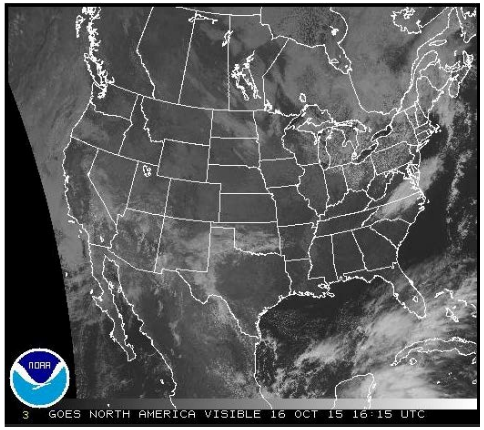
The fence is scheduled to begin operating in 2018, with construction of the first

# Why should the General Public Care?

- Satellites are used by everyone, every day

- Weather forecasts and storm monitoring
- Television distribution
- Communications
- GPS – location and time reference
- Scientific discoveries


- Orbital debris can disrupt or destroy any of these services
  - Collisions
  - ‘Graceful degradation’
  - Eventually making launches much more risky

# Reality Check

## Space is still pretty big - mostly

- We're not talking about daily major crises
  - We work to a 1% probability of a penetration that would prevent the planned disposal
- Only about a 50/50 chance of it ever happening on a NASA mission
- No known case to-date of a NASA spacecraft being fatally struck
- Benign hits might happen frequently, though, without our knowledge
- Benign impacts might still result in shorter or reduced missions
- Daily conjunction assessments help to prevent collision with large (>10 cm) objects

- Fortunately, the cascade portrayed in Gravity wouldn’t take place nearly as fast as in the movie

**The real risk is the long-term (decades) loss of access to the orbital environment**

# A Sample of NASA Missions
## (a wealth of diversity)

- Quantity
  - Currently 43 Space Science, 27 Earth Science, and 9 TDRS missions actively operational, with 23 more in development – ~100 total missions, including development
- Orbits
  - Many in LEO (most 400 to 850km)
  - A few in GEO
  - Some high eccentricity, L1 and L2
  - Lunar and Mars
- Propulsion – About 60% have propulsion systems
- Construction

- Many high Z materials in detectors
- Substantial use of Titanium
- Glass mirrors and lenses

# ORBITAL DEBRIS PROTECTION

Protecting the spacecraft from debris damage

## Methods of Protection

Mission Design

# Hardware Design

# Shielding

# Conjunction Assessment

# Mission Design and Ops Considerations

- **<u>Orbital debris needs to be considered early</u>**

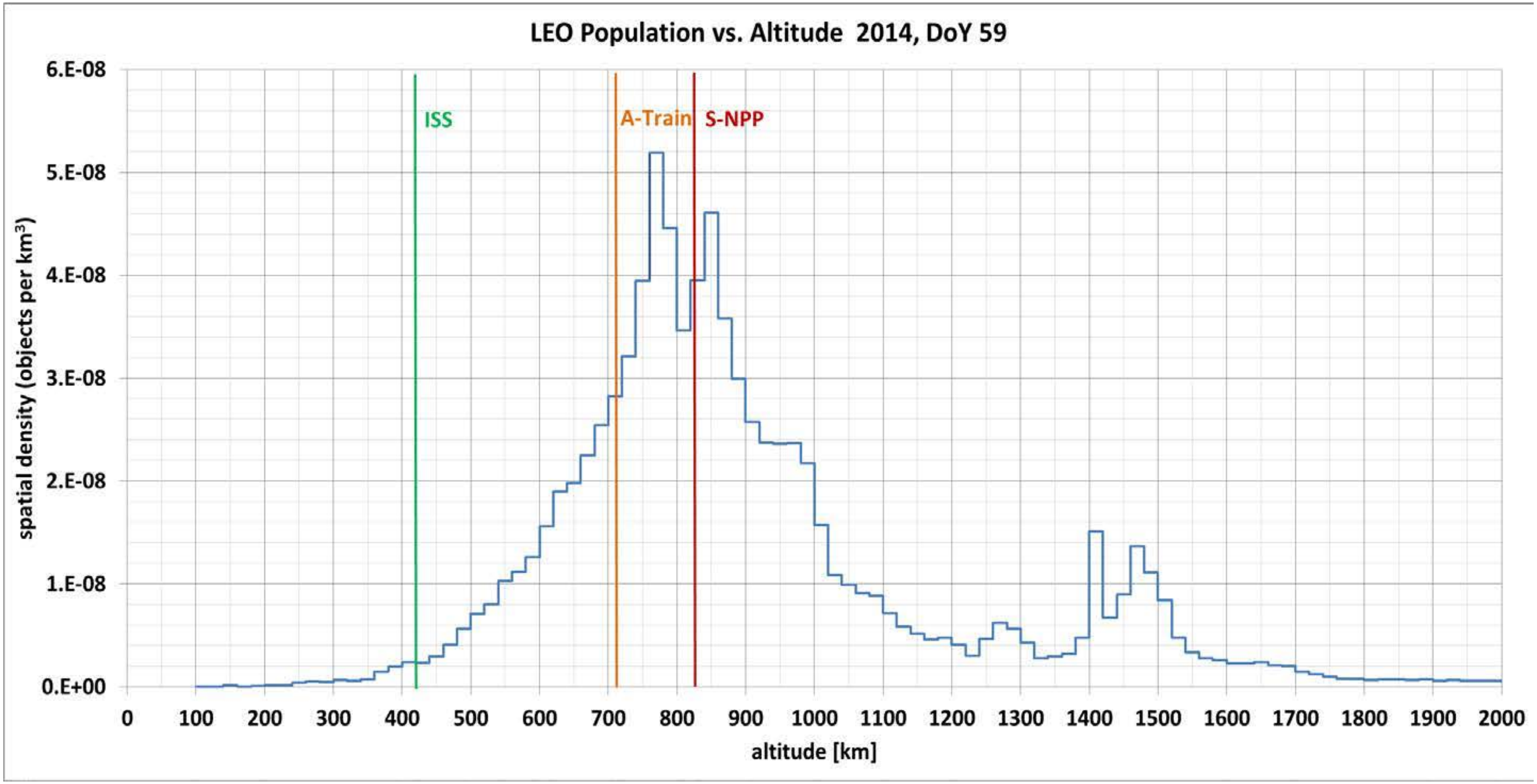
- **Orbit selection**
  - Avoid debris peaks at ~750, 900, and 1400 km
  - Orbit selection is usually driven by science needs

    Then again, science can be difficult in a minefield…

- **Operations**
  - Debris avoidance maneuvers to avoid predicted close approaches

– Reorient the spacecraft during meteor showers or close approaches

# Debris Density vs. Altitude


LEO Population vs. Altitude 2014, DoY 59
ISS
A-Train
S-NPP
spatial density (objects per km³)
6.E-08
5.E-08
4.E-08
3.E-08
2.E-08
1.E-08
0.E+00
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
altitude [km]

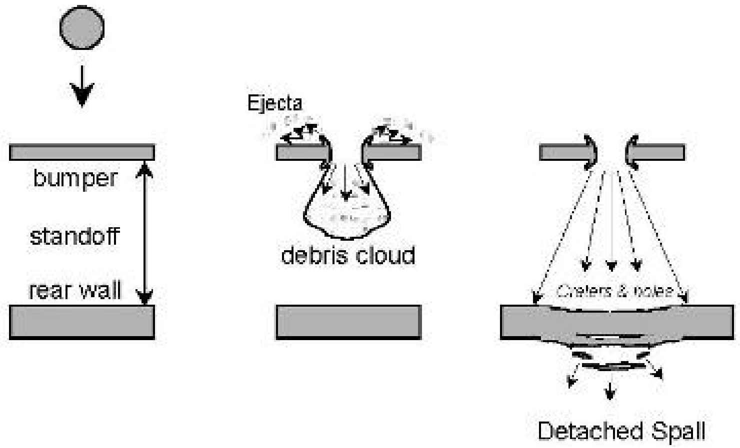
## Hardware Design Considerations

- Component location
  - If possible, locate critical bus components inside the spacecraft
  - Nadir and zenith are lowest exposure
  - Ram direction and sides are highest exposure

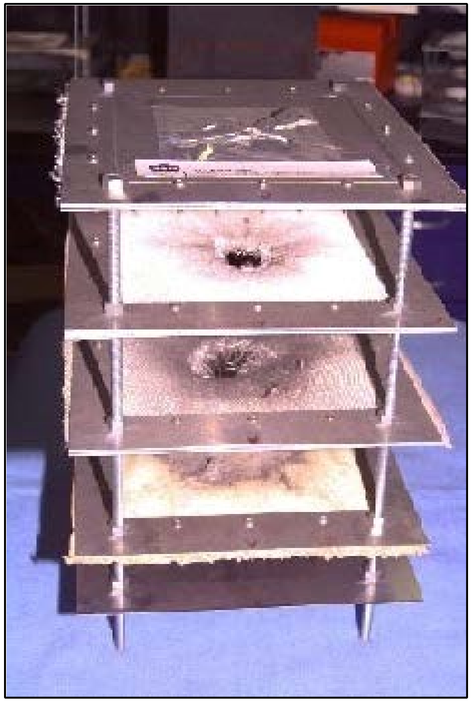
- – Take advantage of shadowing
- Wall thickness
- Add shielding
- Redundancy

# Multi-wall Shield Mechanisms

- 'Bumper' disruptor layer




  - Breaks up and melts projectile
  - High temperature material (Nextel does well)
- Inner stopper layer
  - Traps the slower moving secondary debris
  - High toughness material (Kevlar does well)



- Back wall
  - Usually the box wall
  - Provides the last line of defense
  - Can generate spalling from inside surface, even if not penetrated

# ORBITAL DEBRIS PREVENTION

Protecting space from us…

# Prevention Methods

- Design for Safety
- End of Mission Disposal
  - Reentry (active or passive)
  - Storage orbits
- End of Mission Passivation
  - Disconnect battery
  - Vent pressure sources

– Essentially minimize residual stored energy

# Design for Safety During and After the Mission

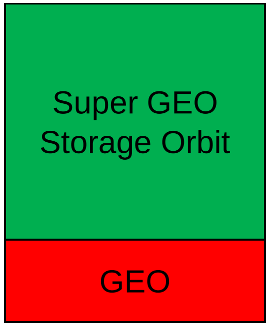

- Propellant and pressurant venting hardware
  - Especially important with bipropellant systems
- Pressure tank design
  - Burst strength $\geq$2X MEOP recommended
- Battery selection
  - Usually driven by power demands
  - Ni-$H_2$ can be an explosion risk if overcharged
  - Li-ion less susceptible, but has strict charging considerations

- Locate pressurized components near center of spacecraft
  - Protection against debris strikes – Any fragmentation is more contained

- **BUILD IN AN OFF SWITCH**

- Perform a responsible disposal at the end of the mission

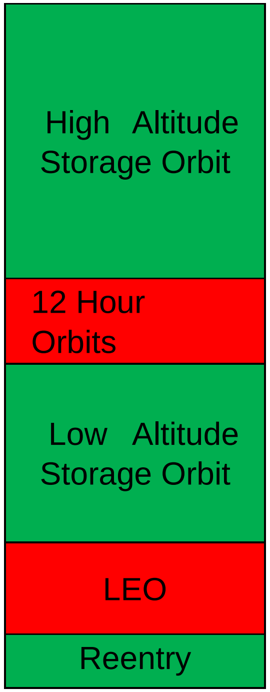
# Postmission Disposal Methods



- Reentry
  - Controlled or uncontrolled
  - With or without orbit lowering
  - Depends on reentry risk, orbit, propulsion capacity, guidance reliability

- Storage orbit
  - Can stay in LEO up to 25 years
  - 2000 km to GEO-200 km
  - Above GEO+200 km

- Retrieval



# Power System Passivation

- Requires designing in an “off-switch” early

- Disconnect solar arrays (preferred)
  - Can be easier/safer to achieve
  - Passivates all electronic equipment at once
- Disconnect the battery from the charging circuit
  - Relays, instead of logic
  - Reducing charging rate is not enough
- Leave small loads attached

- Disable failure detection and correction modes at EOM
- Never recharge Li-ion after a deep discharge

## Pressure Tank Passivation

- Requires designing in venting hardware

- Design for venting
  - Bypass around diaphragms
  - Add vent lines for isolated pressurant
  - Consider effects of cold gas thrust

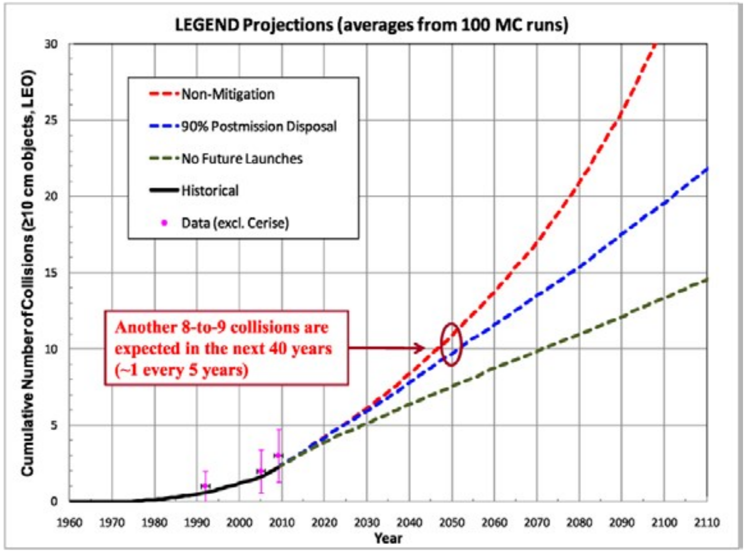
– Redundant valves in series on vent lines to prevent single point of failure

- Vent pressure as much as practical
  – Latching valves left open if possible
  – Very small amount often remains

# DEBRIS REMOVAL

What might the future bring?

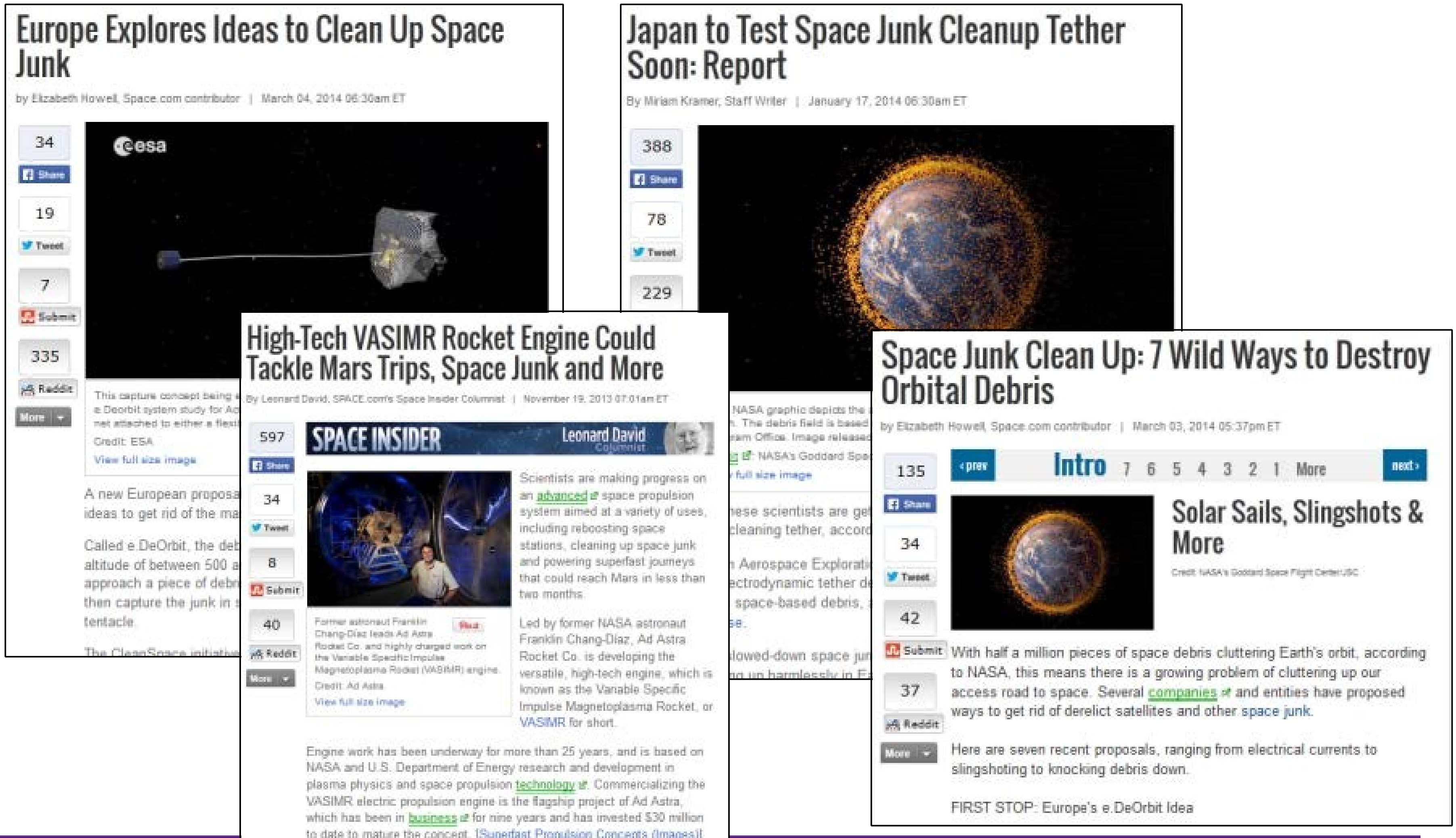
## Recent Ideas




- Removing debris to prevent collisions from occurring
- Delay or avoid the Kessler Syndrome
- Process
  - Launch and rendezvous (harder than it sounds)
  - Capture the debris (LOTS of ways to do this)
  - De-orbit to a safe region (usually the ocean)
- Size

- Emphasis is on removing large objects, to have greatest effect
- Some ideas for ‘sweeping’ small debris as well

# Debris Removal Articles


Europe Explores Ideas to Clean Up Space Junk
by Elizabeth Howell, Space.com contributor | March 04, 2014 06:30am ET
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Japan to Test Space Junk Cleanup Tether Soon: Report
By Miriam Kramer, Staff Writer | January 17, 2014 06:30am ET
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High-Tech VASIMR Rocket Engine Could Tackle Mars Trips, Space Junk and More
By Leonard David, SPACE.com's Space Insider Columnist | November 19, 2013 07:01am ET
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Scientists are making progress on an advanced space propulsion system aimed at a variety of uses, including reboosting space stations, cleaning up space junk and powering superfast journeys that could reach Mars in less than two months.
Former astronaut Franklin Chang-Diaz leads Ad Astra Rocket Co. and highly charged work on the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) engine.
Credit: Ad Astra
View full size image
Led by former NASA astronaut Franklin Chang-Diaz, Ad Astra Rocket Co. is developing the versatile, high-tech engine, which is known as the Variable Specific Impulse Magnetoplasma Rocket, or VASIMR for short.
Engine work has been underway for more than 25 years, and is based on NASA and U.S. Department of Energy research and development in plasma physics and space propulsion technology. Commercializing the VASIMR electric propulsion engine is the flagship project of Ad Astra, which has been in business for nine years and has invested $30 million to date to mature the concept. [Superfast Propulsion Concepts (Images)]
Space Junk Clean Up: 7 Wild Ways to Destroy Orbital Debris
by Elizabeth Howell, Space.com contributor | March 03, 2014 05:37pm ET
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Solar Sails, Slingshots & More
Credit: NASA's Goddard Space Flight Center/JSC
With half a million pieces of space debris cluttering Earth's orbit, according to NASA, this means there is a growing problem of cluttering up our access road to space. Several companies and entities have proposed ways to get rid of derelict satellites and other space junk.
Here are seven recent proposals, ranging from electrical currents to slingshoting to knocking debris down.
FIRST STOP: Europe's e.DeOrbit Idea

# So, why aren't we doing it already?

- Cost
  - Generally about $50M to $100M per large object removed
    - Who pays?  Debris owner?  All space users?
  - Some have proposed a tax on future launches
  - Still seems prohibitive
- Legal restrictions
  - Who owns the debris object? (jurisdiction as well as liability)

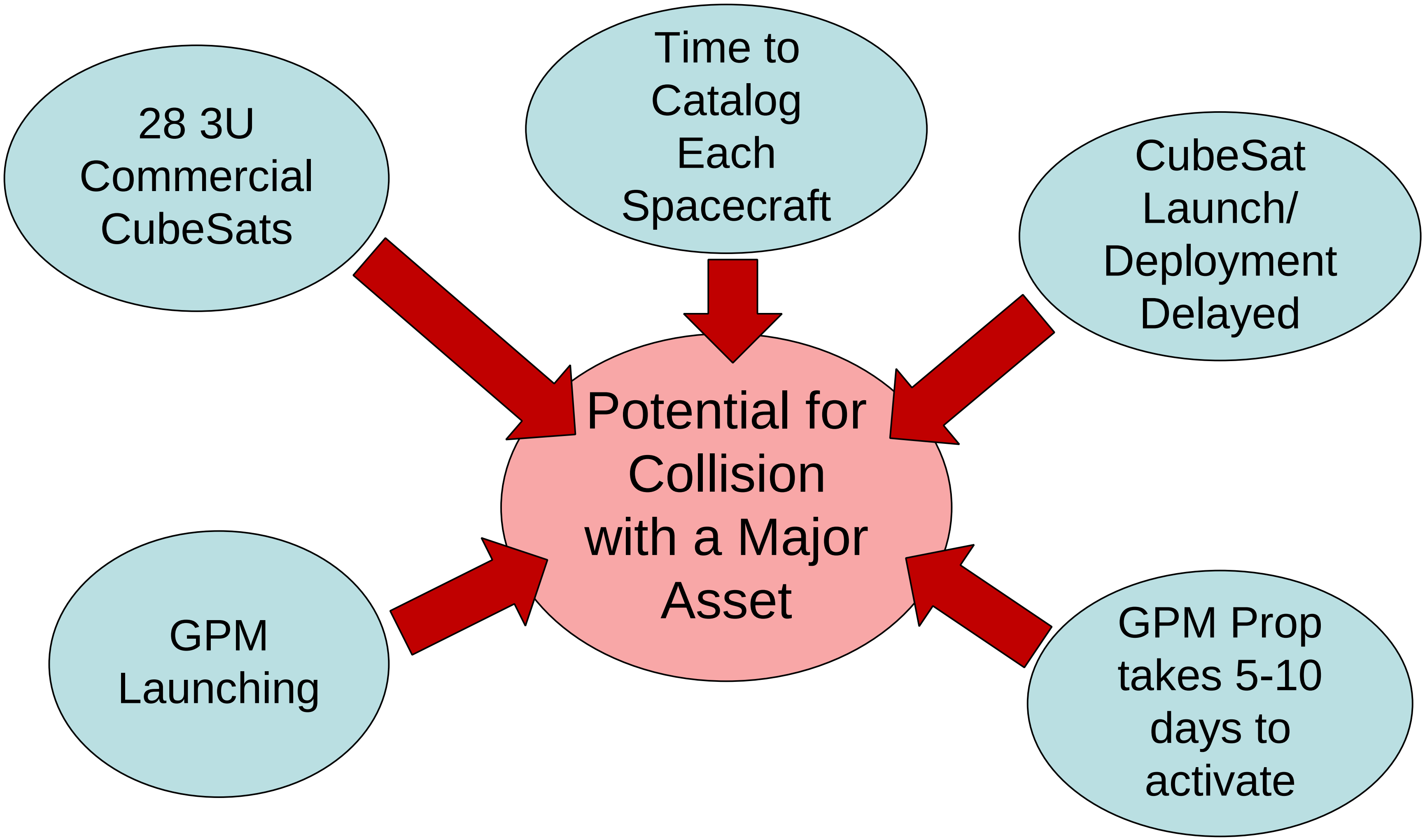
– One man’s deorbit mission is another man’s space weapon

- Not a ‘today’ problem
  – The current rate of accumulation has been manageable, so no one is investing money in preventing the inevitable increase.

# RECENT EVENTS

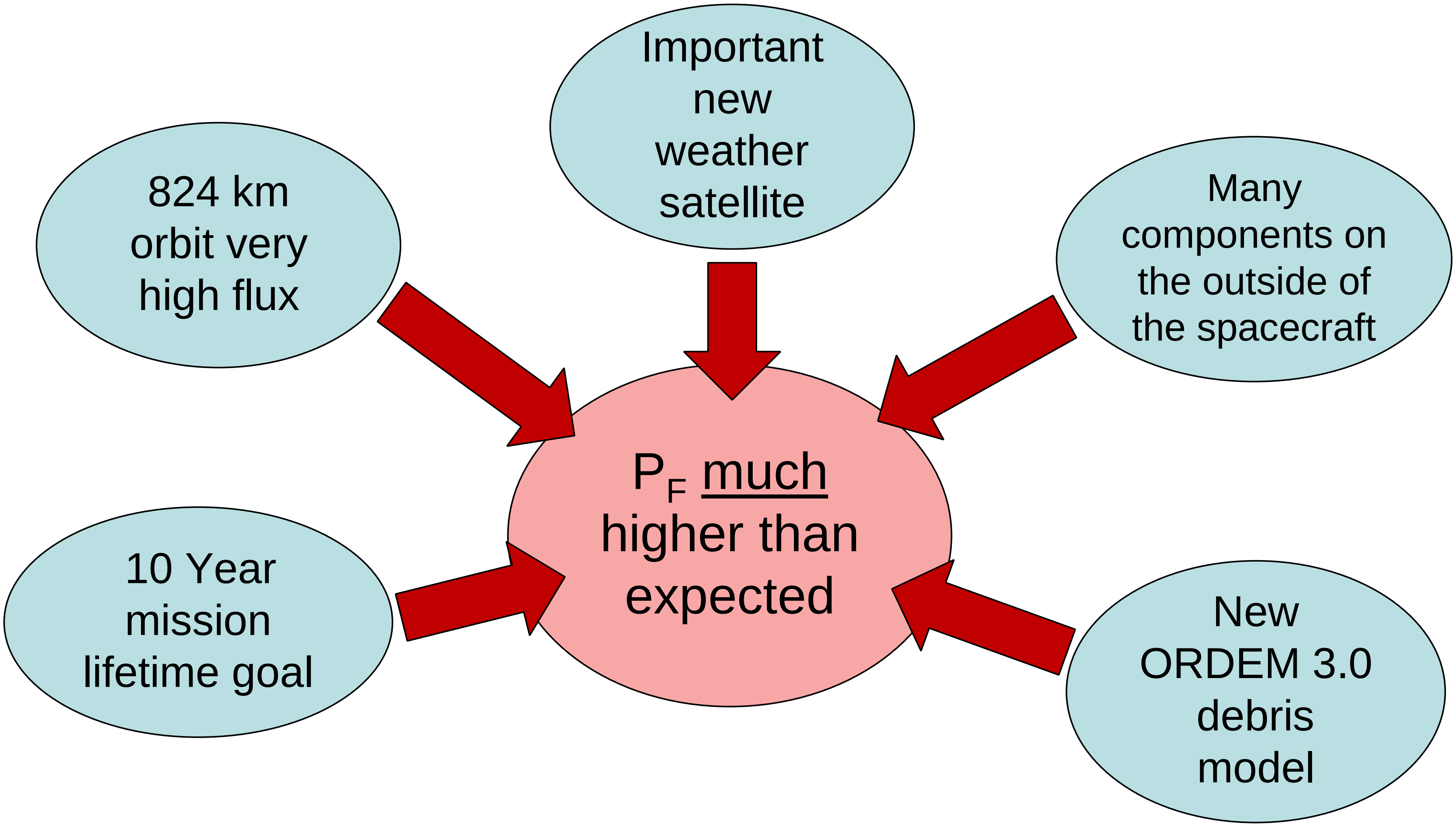
A couple war stories…

# Recent 'Perfect Storm' #1
# Potential Collision Concern


28 3U Commercial CubeSats
Time to Catalog Each Spacecraft
CubeSat Launch/ Deployment Delayed
Potential for Collision with a Major Asset
GPM Launching
GPM Prop takes 5-10 days to activate

# Recent ‘Perfect Storm’ #2

# JPSS-1 Small Object Collision Assessment


Important new weather satellite
824 km orbit very high flux
Many components on the outside of the spacecraft
$P_F$ much higher than expected
10 Year mission lifetime goal
New ORDEM 3.0 debris model

# Conclusions (1 of 2)

- The accumulation of debris in operational orbits is a real and growing concern.
- Collisions will dominate the generation of additional debris in the future.
- There are design techniques for protecting most spacecraft and instruments from the effects of orbital debris.

- Eventually, though, that won’t be enough

# Conclusions (2 of 2)

- While it is presently impractical to remove derelict objects from orbit, there are agreements and requirements in place to help limit the addition of more debris.

- Disposal and passivation planning are critical to limiting the long-term rate of debris growth, as will be removal.

- Orbital debris accumulation isn’t a crisis today, but the sooner we act, the more effective solutions can be.

# Questions